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Polarization study of the pulsars in the globular cluster 47 Tucanae

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Abstract. The linearly polarized component of a pulsar signal at different radio frequencies can help to constrain the parallel component of the magnetic field along the line of sight. In this work we measured the polarimetric properties of the pulsars in the globular cluster 47 Tucanae and we report the Rotation Measure (RM) for 13 of them. A gradient in the RM values of the pulsars across the cluster is detected suggesting the presence of significant variations in the magnetic field across the very small angular scales associated with the lines of sight to the pulsars in 47 Tucanae. Both magnetic fields located in the globular cluster or in the Galactic disk in the direction of the cluster are taken into consideration. However, more detailed modelling of the dynamics of the cluster and deeper observations with the MeerKAT and/or the SKA1 radio telescopes are necessary to discriminate among the models.

Keywords. globular clusters: individual: 47 Tucanae, pulsars: individual:PSR J0024-7203C to J0024-7204Y, polarization, magnetic fields

1. Introduction

Globular clusters are gravitationally bound spherical stellar systems typically found in the bulge or halo of the galaxies. These are some of the densest stellar systems known with mass densities in the core up to $10^6\ M_\odot \mathrm{pc}^{-3}$. The extreme environments in the core make these systems excellent breeding grounds for the formation of recycled millisecond pulsars.

The precise timing of a large population of pulsars in a globular cluster can help to determine a large number of properties of the cluster that would otherwise be undetectable. In this regard, the Dispersion Measure (DM) and the Rotation Measure (RM) are of particular importance. The DM is the relative delay in the time of arrival of the pulses at different frequencies and is caused by the ionized medium along the line of sight to the pulsar. If this ionized medium has a magnetic field with a component parallel to the line of sight, the linearly polarized part of the pulsed radio signal will also undergo Faraday rotation, which is a rotation of the linear polarization position angle. This rotation will depend on the integrated intensity of the magnetic field and on the column density of the ionized medium. Studies of the DM of the pulsar in a globular cluster can detect ionized medium inside the cluster. This was done for the first time for the globular cluster 47 Tucanae (Freire *et al.* 2001). Instead, studies of the RM can help constrain for

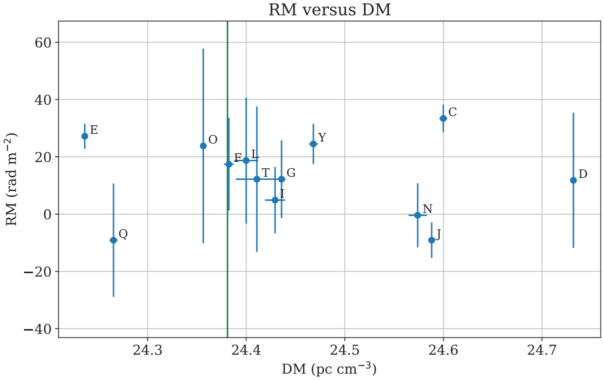

Figure 1. Plot of RM as a function of DM. The vertical green line is the central value of DM as measured by Freire *et al.* (2001). The errors are at two sigma.

the first time a magnetic field inside a globular cluster and/or reveal magnetic turbulence of the Interstellar Medium (ISM) on the very small scales associated with the projected position of the pulsars in the cluster. A similar study has been undertaken for the pulsar in the globular cluster Terzan 5 (Ho *et al.* 2013).

The cluster we selected to conduct this analysis is 47 Tucanae. It is one of the most prominent globular cluster in the sky and contains 25 millisecond pulsars (Pan *et al.* 2016). For 23 of them it was possible to obtain phase coherent timing solutions (Ridolfi *et al.* 2016, Freire *et al.* 2017). Almost all of them are located in the central region of the cluster (i.e. within a diameter of $\sim$ 2 arcmin). The aim of this work is to measure the polarimetric properties of the pulsars of 47 Tucanae, test for the presence of a magnetic field internal to the cluster and study the magnetic turbulence of the ISM.

2. Results

The globular cluster 47 Tucanae was observed with the Parkes radio telescope over a time span of almost a year from April 2014 to March 2015. The observations were carried out in full polarization at a central frequency of 1382 MHz with the central beam of the Multibeam receiver and recorded with the CASPSR backend. The data were analized using the PSRCHIVE software package (Hotan, van Straten & Manchester 2004, van Straten, Demorest & Olsowski 2012). The RM values values were obtained with a code written following the prescriptions described in Tiburzi *et al.* (2013). The errors on RM were estimated using a Monte Carlo simulation and the results were compared to what was obtained with the PRSCHIVE tool *rmfit* using the implementation described in Han *et al.* 2006. It was possible to obtain RM values only for 13 pulsars as the others were either too weak or did not show bright polarization.

The measured values of RM of the pulsars are plotted in Fig. 1 as a function of their DM values. There is a large scatter in the measures of RM that can be caused either by variations along the line of sight of the electron number density or by variations in the parallel component of the magnetic field. Both DM and RM depend on the same way on the electron density. Since there is no linear correlation between these two quantities visible in Fig. 1, the RM scatter cannot be due to the electron density but must be due to a magnetic field.

A possible relation between the RM values and the positions of the pulsars on the plane of the sky was investigated. We projected the position of the pulsars along an axis and checked for linear correlation between the RM and this projection. Then we

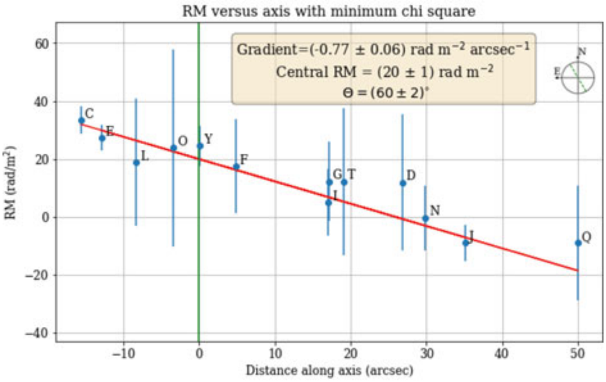

Figure 2. Plot of RM as a function of the distance of the pulsars projected along the best axis. This axis has an angle of 60° measured from East to North and is shown in the top right corner of the plot. The vertical green line corresponds to the optical center of the cluster as measured by Mclaughlin *et al.* (2006). The errors are at two sigma.

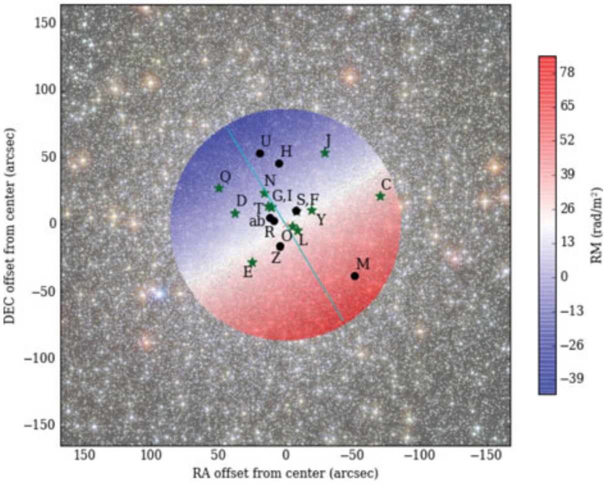

Figure 3. Model of the RM we expect to see if the observed gradient were constant throughout the cluster. The cyan line indicates the direction of the measured gradient. The green stars represent the pulsars with a measured RM, the black dots the ones without a measured RM.

changed the orientation of the axis to find the best possible correlation. This fit was performed simultaneously on the parameters of the linear correlation and on the angle with a Markov Chain Monte Carlo (MCMC). The angle of the best axis is found to be: $\theta = 60 \pm 2$ deg, the central value of RM is (20 ± 1) rad m^{-2} and the slope of the gradient is (-0.77 ± 0.06) rad m^{-2} arcsec^{-1}. The results of the fit are shown in Fig. 2. The intensity and direction of the observed gradient is visualized by the model presented in Fig. 3.

3. Discussion

The analysis of the polarized radiation of the pulsars in the globular cluster 47 Tucanae suggests the presence of a magnetic field which is changing across the lines of sight of the pulsars. The magnetic field could be located inside the globular cluster or in the Galaxy along the line of sight. Through the use of the structure function it is possible to test whether the observed variations of RM are caused by a regular or turbulent magnetic field. However due to the large errors, this test turned out to be inconclusive. In the rest of the discussion we will assume that the magnetic field is regular.

The distribution of the observed RM is compatible with a linear gradient across the central region of the cluster. This gradient could be caused by a magnetic field inside the globular cluster but the required intensity of the field would be $\sim 150\,\mu$G. This corresponds to $\sim 1-2$ orders of magnitude greater than the equipartition value measured with the properties of the cluster found in McDonald & Zijlstra (2015). The gradient could also be originating from a magnetic field outside the globular cluster. The direction of the gradient is almost perpendicular to the Galactic disk. One possibility is that it arises from the interactions of an outflowing wind from the Galactic disk and the globular cluster itself.

No definitive answer around the origin of the magnetic field can be given with the available data. However, more detailed modelling of the dynamics of the pulsars in the cluster could help to better test the case of an internal magnetic field. Better results could come from the new radio telescopes under construction in the southern hemisphere like MeerKAT and later SKA1-MID. MeerKAT will have a collecting area that is ~ 3 times larger than Parkes. This and the increased bandwidth could significantly improve the quality of the data reducing the errors for the pulsars presented here and measuring the RM for the rest of the pulsars. The improvement with SKA1-MID will be even greater as the collecting area will be ~ 10 times that of Parkes. Observations with these telescopes could play a decisive role in determining the origin of the magnetic field.

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References

Booth, R. S. & Jonas J. L. 2012, *African Skies*, 16, 101

Camilo, F., Lorimer, D. R., Freire, P. Lyne, A. G., & Manchester R. N. 2000, *ApJ*, 535, 975

Camilo, F. & Rasio, F. 2005, *ASP-CS*, 328, 147

Freire, P., Kramer, M., Lyne, A. G., Camilo, F., Manchester R. N. & D'Amico, N., 2001 *ApJ*, 557, L105

Freire, P., Ridolfi, A., Kramer, M. *et al.* , 2017 *MNRAS*, 471, 857

Han, J. L., Manchester, R. N., & Lyne, A. G. *et al.* 2006, *ApJ*, 642, 868

Ho, A., Ransom, S. M., & Demorest, P. 2013, *American Astronomical Society*, AAS Meeting 221

Hotan, A. W., van Straten, W. & Manchester R. N. 2004, *PASA*, 21, 302

McDonald, I. & Zijlstra, A. A., 2015 *MNRAS*, 446, 2226

McLaughlin, D. E., Andreson, J., Meylan, G., Gebhardt, K., Pryor, C., Minniti, D., & Phinney, S. 2006, *ApJS*, 166, 249

Oppermann, N., Junklewitz, H., & Greiner, M. *et al.* 2015, *A&A*, 575

Pan, Z., Hobbs, G., Li, D., Ridolfi, A., Wang, P., & Freire, P. 2016, *MNRAS*, 459, L26

Ridolfi, A., Freire, P., & Torne, P. *et al.* 2016, *MNRAS*, 462, 2918

Tiburzi, C., Johnston, S., & Bailes, M. *et al.* 2013, *MNRAS*, 436, 3557

van Straten, W., Demorest, P., & Oslowski, S. 2012, *Astronimcal Research and Technology*, 9, 237